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## Equation Solvers for Distributed Memory Computers

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by Olaf O. Storaasli, (O.O.Storaasli@larc.nasa.gov or 804-864-2927)

for Workshop on the Role of Computers in Langley R&D (6-15-94)

A large number of scientific and engineering problems reduce to the solution of large systems of simultaneous equations. Solving large systems of simultaneous equations rapidly thus makes the solution of large-scale structures, physics, electromagnetics and fluid mechanics problems tractable. The performance of parallel computers now dwarfs traditional vector computers by nearly an order of magnitude, so the challenge is to rapidly solve large systems of equations rapidly on the new breed of scalable parallel processing supercomputers.

Research at Langley on solving equations on distributed memory computers goes back nearly ten years to the Langley Finite Element Machine, one of the nation's first parallel computers with 32 processors developed by NASA before commercial parallel computers were available. Since then, both iterative and direct parallel equation solvers have been developed and tuned for parallel computers manufactured by Flexible computer, N-Cube, Alliant, Encore, Cray, Intel, Convex and IBM. The solvers, PVSOLVE and PVS-MP are currently running on the IBM SP-1 and SP-2 under a Memorandum of Agreement with IBM which permits Langley early access to the SP-1 and SP-2 in return for IBM given permission to use the NASA solvers for advertisements, demonstrations, and trade shows. These Langley solvers are timely since in a recent \$22.4 million procurement, two IBM SP-2 supercomputers will be delivered to NASA (160 processors to NAS and 48 processors to LaRC). Based on benchmarks and the Langley parallel equation solvers, these IBM supercomputers promise to surpass the performance of traditional Cray vector supercomputers and other parallel computers.

The talk will describe the major issues involved in parallel equation solvers with particular emphasis on implementations the Intel Paragon, IBM SP-1 and SP-2.



## Equation Solvers for Distributed-Memory Computers

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Mail Stop 240

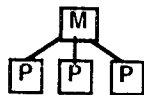
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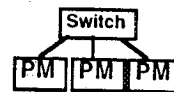
presented at

Workshop on

The Role of Computers in Langley R&D

June 15, 1994, Reid Auditorium

Langley Research Center



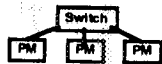
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## Objective

- *Faster, cheaper, better* analysis/design of large-scale structures
  - Develop algorithms to exploit distributed-memory computers
  - Evaluate computational performance



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## Outline



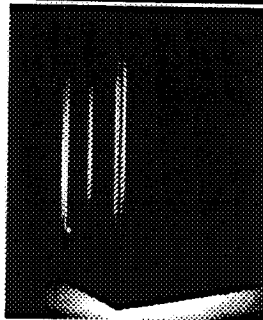
- Distributed-memory Computers
- Structural Applications
- Structural Analysis
  - - Nodal Generation and Assembly
  - - Linear Equation Solvers
- Structural Optimization
- X-Design Sensitivity



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## 1994 Distributed-Memory Supercomputers

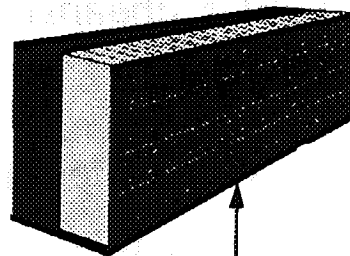
### IBM SP-2



Being installed this summer at  
NAS (160 proc)  
and LaRC ( 48 proc)  
266 MFLOPS/proc peak



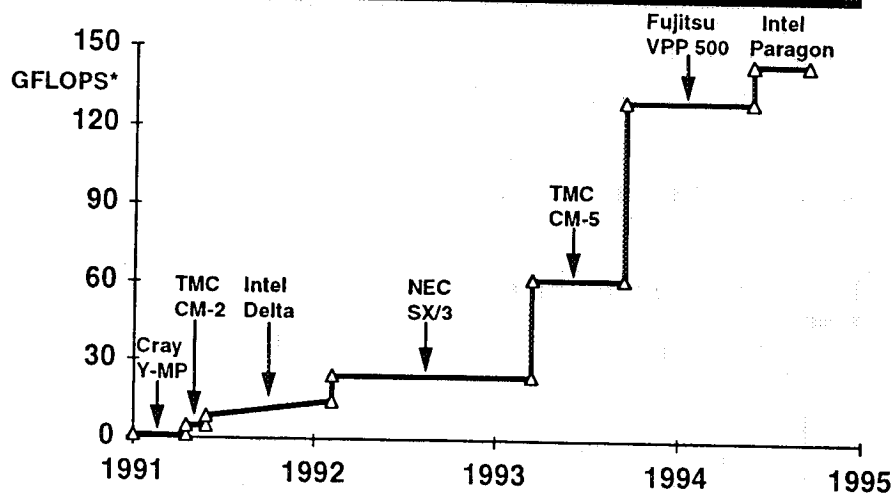
### Intel Paragon



Current world record holder!  
143 GigaFLOPS for MP-Linpack

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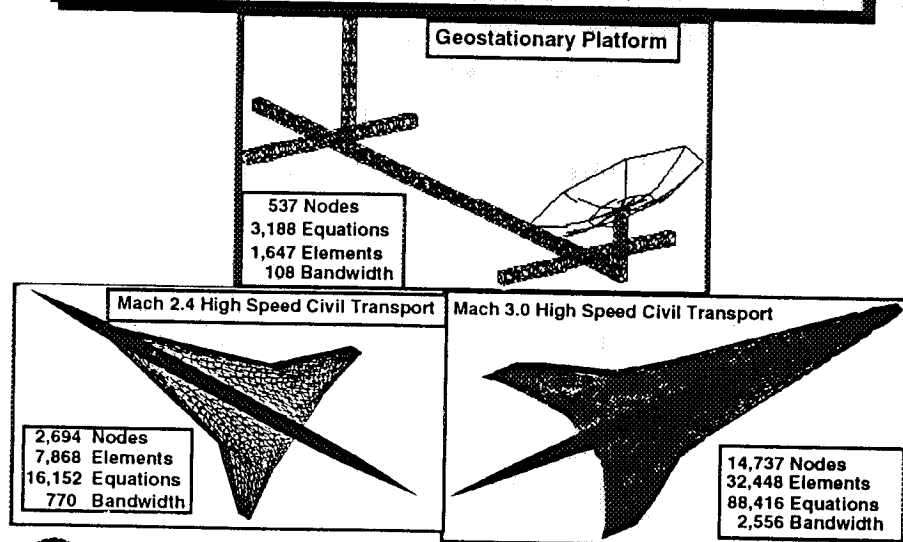
## Record MP-Linpack GFLOPS\*



\* billion floating point operations per second

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## Performance Assessment Applications



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## Parallel Matrix Generation and Assembly

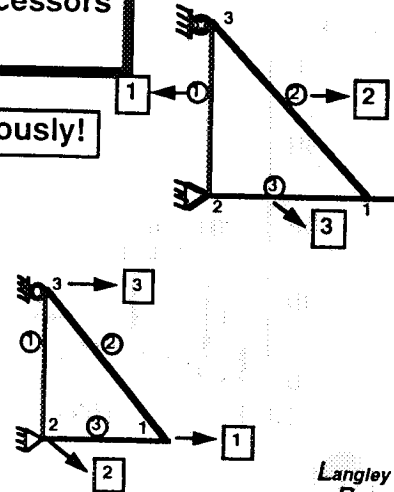
By element: Traditional thinking  
Generate  $[k^{(e)}]$  on different processors  
Assemble global  $[K] = \sum [k^{(e)}]$

can't write elements simultaneously!

By node: New method

Nodal Connectivity

Node	Proc.	Elements
1	1	② ③
2	2	① ③
3	3	① ②



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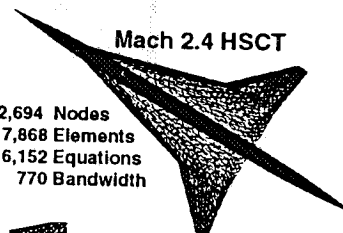
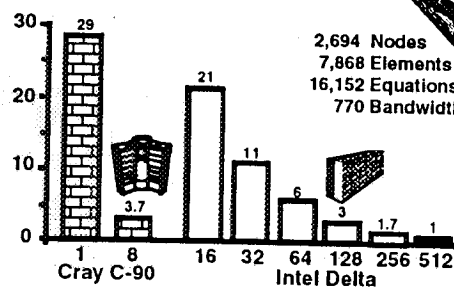


## Parallel Structural Matrix Generator/ Assembler Demonstrated on HSCT



- Nearly ideal parallel speedup  
(no interprocessor communication)

Time  
(Sec)



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## Equation Solution Issues

(Time, memory, disk space, I/O)



- Iterative or direct ?
- Banded or sparse ?
- "In-core" or "out-of-core" ?

### Communication

- Broadcast or ring?
- OSF or SUNMOS?



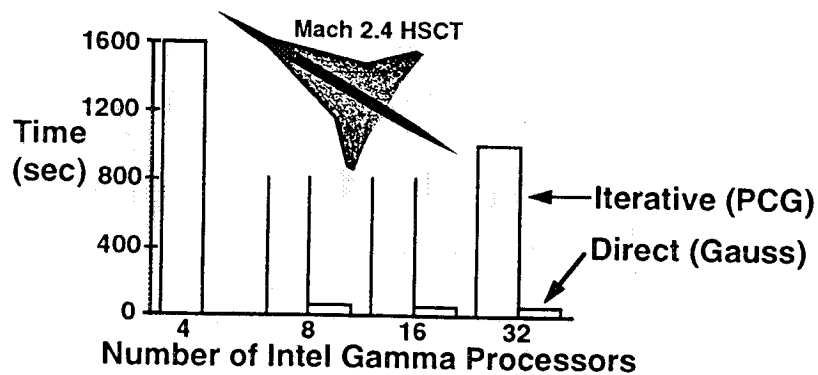
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## Iterative vs Direct Solvers

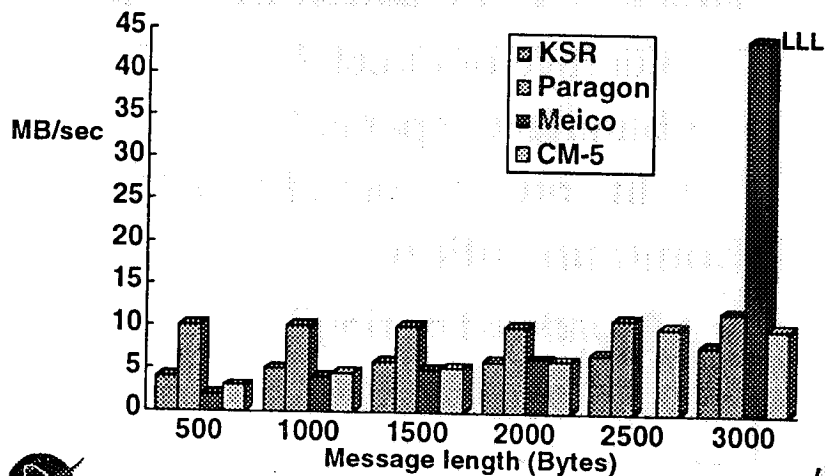


- Iterative slow, convergence not guaranteed
- Direct complex coding (banded, sparse)



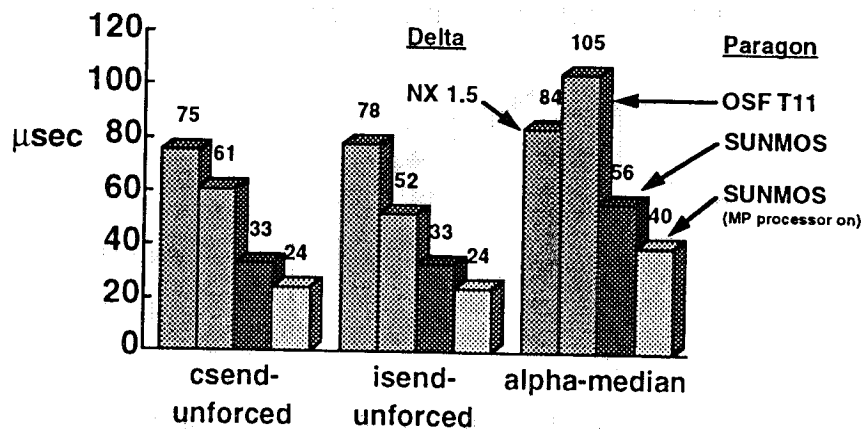
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## Interprocessor Communication



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## Latency OSF vs SUNMOS



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## Paragon Status



- **OSF Rev 1.1** (Latency: 150  $\rightarrow$  85  $\mu$ sec, Tools Communication: 11  $\rightarrow$  34 MB/sec, Memory 8  $\rightarrow$  6MB)
- **OSF Rev 1.2** (Latency: 85  $\rightarrow$  50  $\mu$ sec  
Communication: 34  $\rightarrow$  55 MB/sec)
- **New comm chip:** tested at 400 MB/sec
- **Dynamic Memory:** avoid inconsistencies  
(i.e. faster 2nd runs)
- **SUNMOS:** Sandia-UNM O/S  
(Latency: 24  $\mu$ sec, Comm: 175 MB/sec, Mem: 0.3MB)  
178 MB/sec on Grace (NAS benchmarks run faster)

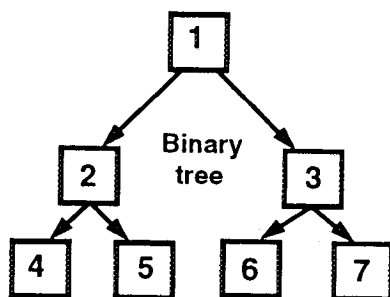


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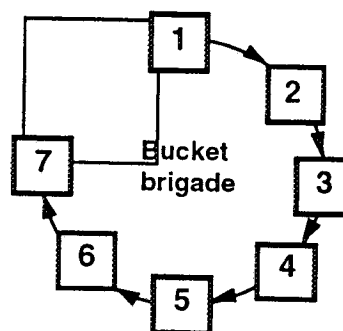
## Interprocessor Communication Methods

### Broadcast

(widely used)



### Ring



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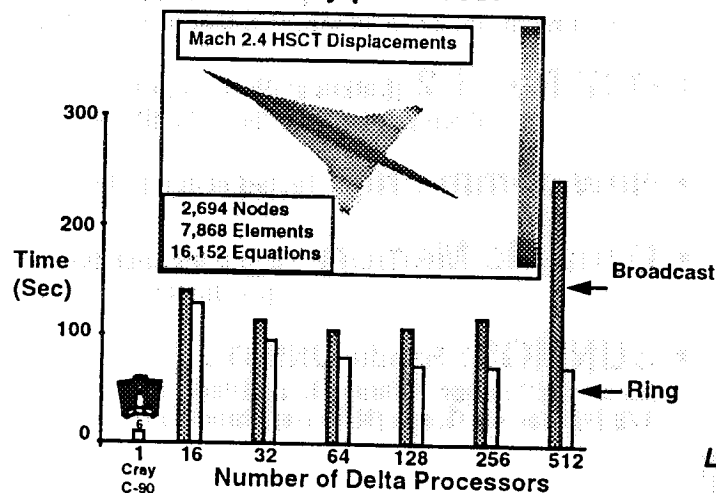




## Solution Time: Mach 2.4 HSCT



- Ring communication reduced solution time
- Slower than 1 Cray processor



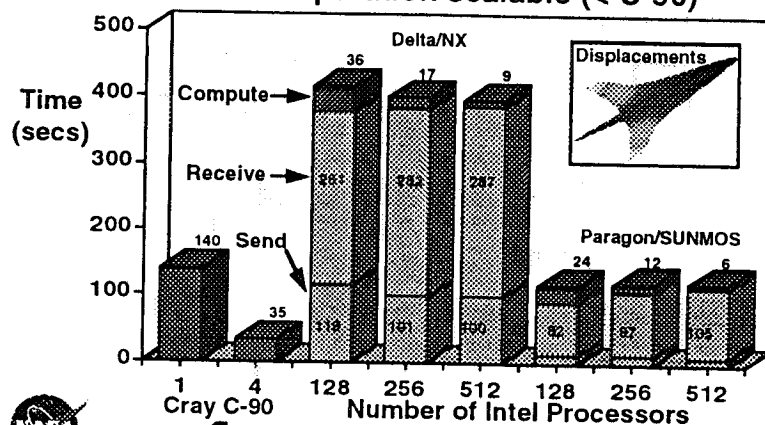
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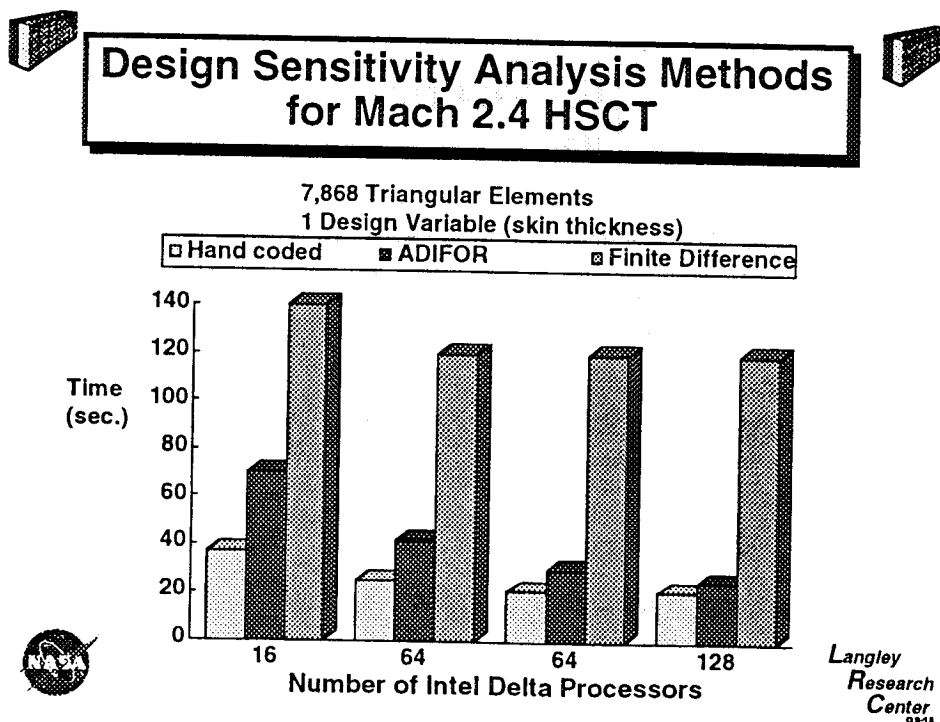
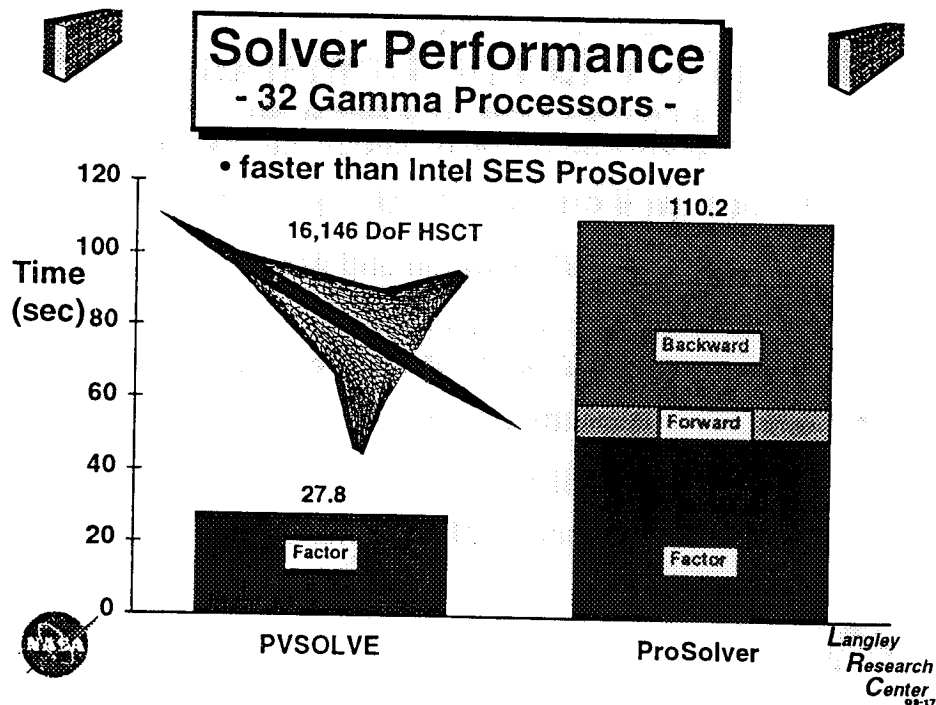
## Solution Time Breakdown - Mach 3.0 HSCT -



- Communication dominates
- Computation scalable (< C-90)



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- Free Videotape from: shguez@nas.nasa.gov  
(Santa Huguez at 415-604-4632)
- Questions: O.O.Storaasli@larc.nasa.gov
- on MOSAIC-WWW (Langley Technical Report Server)
- also *International Journal of Computing Systems in Engineering*, Vol. 4, No. 2-4, 1993 pp. 349-354
- *Conference Proceedings*, Part 2, pp. 772-778, April 1993.
- *34th Structures, Structural Dynamics and Materials*
- *Vector Supercomputers*, AIAA/ASME/ASCE/AHS/ASC
- Computational Mechanics Analysis Tools for Parallel-  
Storaasli, O., Nguyen, D., Baddourah, M. and Qin, J.;

## References



- Operate on Paragon, IBM SP-1 and SP-2i
- Design Sensitivity
- Structural Optimization
- Equation Solvers:  $[K]\{u\} = \{p\}$   
(linear, nonlinear, "out-of core", sparse)
- Nodal Matrix Generation and Assembly
- Perform well on large-scale applications:
- New algorithms for distributed-memory computers

## Concluding Remarks



## **SESSION 5 Automatic Differentiation**

**Chaired by**

**Olaf Storaasli**

- 5.1 Applications of Automatic Differentiation in Computational Fluid Dynamics - Larry Green**
- 5.2 Automatic Differentiation for Design Sensitivity Analysis of Structural Systems Using Multiple Processors - Duc Nguyen, Olaf Storaasli, Jiangning Qin and Ramzi Qamar**